LEO Space Debris Mitigation Using Laser Ablation

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Introduction

Since the first artificial satellite was launched in 1957 a great number of spacecraft have been put into space and a significant fraction of these are still orbiting the Earth as inert vehicles or space debris, Fig. 1. Major collision events between large satellites in Earth orbits have broken-up spacecraft systems and created a massive quantity of space junk – most of which are small particles.

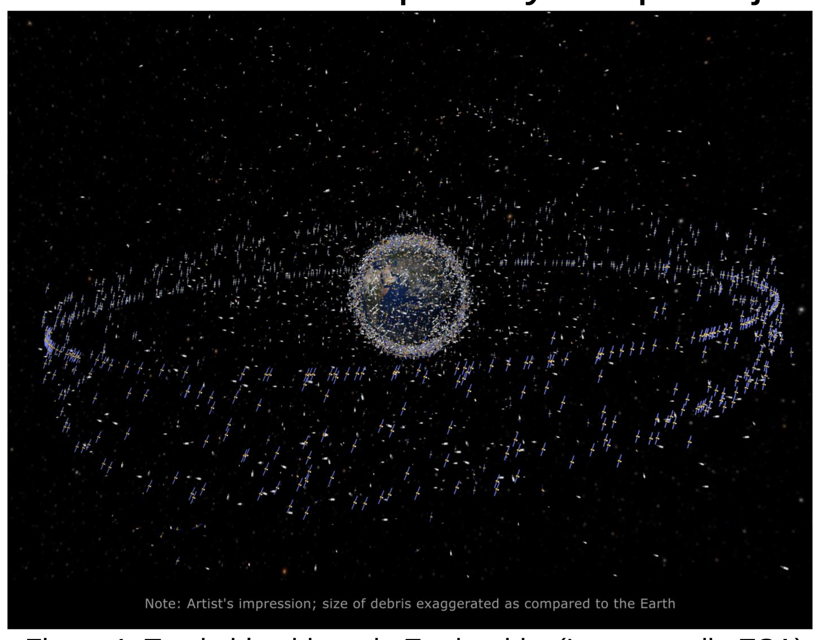

Figure 1: Trackable objects in Earth orbits (Image credit: ESA)

Figure 2: Objects - mostly debris - in LEO (Image credit: ESA)

The number and quantity of debris items is increasing and as a result the probability of catastrophic collisions is growing progressively especially in LEO, Fig. 2. Objects in space, whatever their size, are potentially hazardous and can cause considerable damage, which may disable a space system and produce numerous secondary fragments as a result. Small debris stays in LEO for a very long time (100s years) before re-entering the atmosphere. They quickly burn up as soon as they re-enter the dense atmosphere, whereas large debris may fall down and impact the Earth surface, Fig. 3.

Figure 3: Samples of large space debris that returned and impacted the Earth surface

Measures

Low Earth Orbit (LEO) requires particular attention because this band contains large masses of material orbiting at high relative velocities up to 14 km/s. At this hypervelocity, even small debris < 10 cm, Fig. 4 and Fig. 5, could:

- Cause local damage of an operating satellite
- Disable any space subsystem
- Produce extensive damage to any operational satellite
- Destroy any small satellites

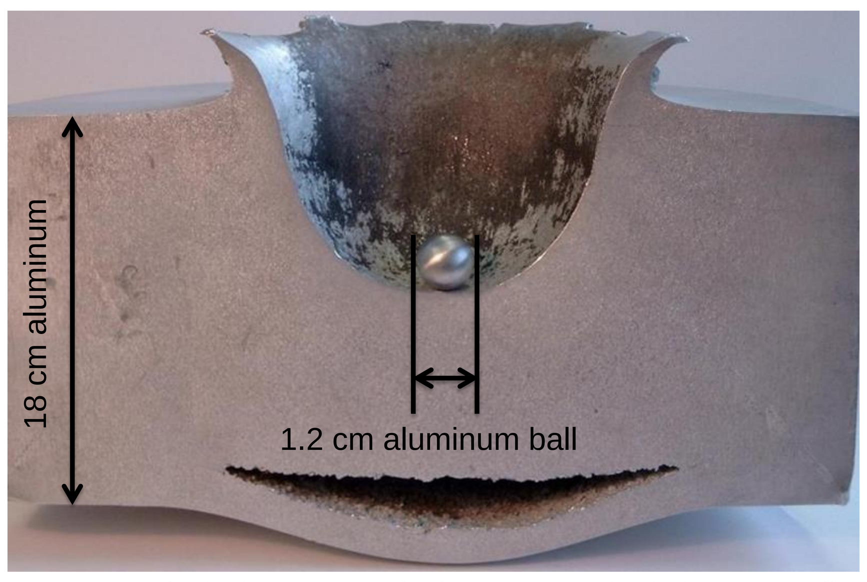

Figure 4: Hypervelocity impact sample, impact at 6.7 km/s (Image credit: ESA)

Therefore, our space assets in LEO are threatened by this large quantity of space junk, which may lead to collision cascading in the future. However, the debris lifetime can be reduced significantly by slowing its velocity slightly and lowering its perigee. This can be achieved by using the unique effect of laser propulsion to generate a small thrust on the debris by hitting it with the necessary energy, Fig, 5.

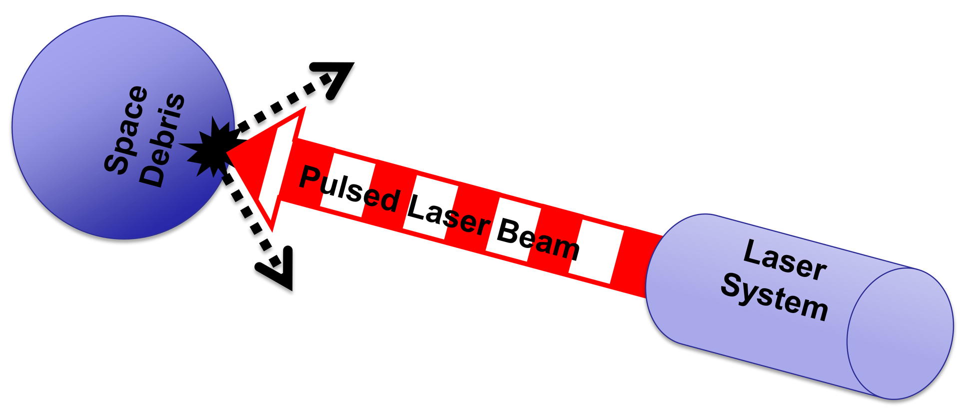

Figure 5: Plume of ejecta produced due to the interaction between laser pulses and object

Results

This paper assessed and simulated the engagement of laser beam pulses with space debris. Fig 6. and Fig. 7 show the required change in orbital velocity (ΔV) of the orbital debris, at different altitudes, to lower its altitude and cause it to change orbit and eventually fall into the upper atmosphere, where it will burn up.

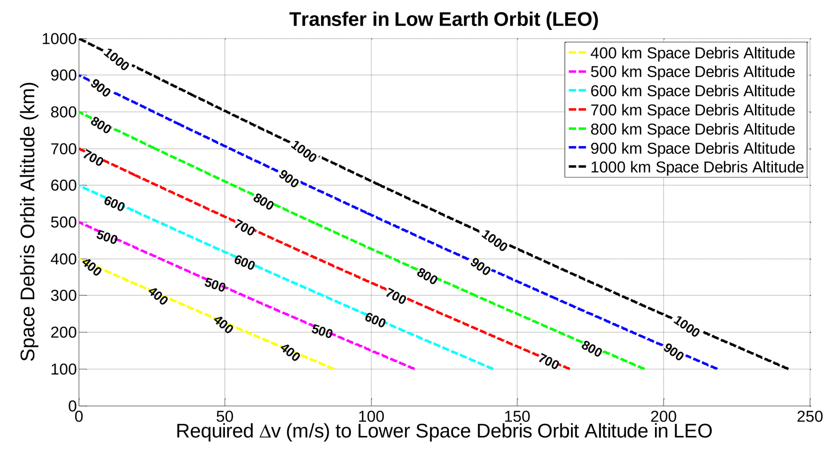

Figure 6: Orbit transfer in LEO (400 - 1000 km initial altitude)

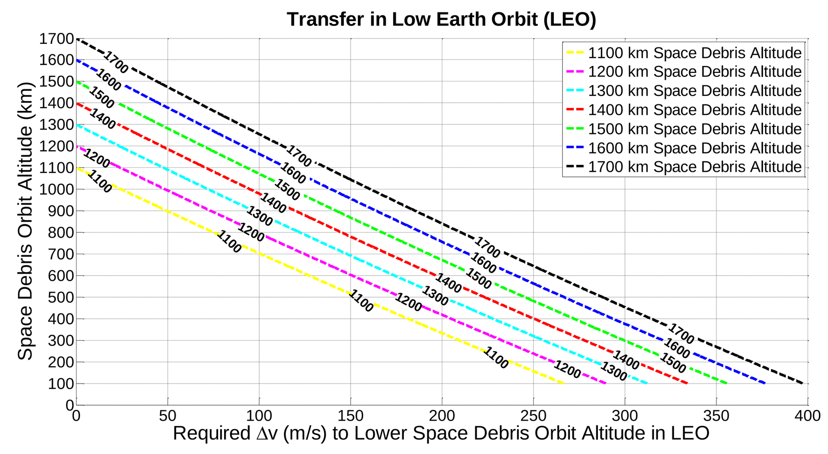

Figure 7: Orbit transfer in LEO (1100 - 1700 km initial altitude)

Understanding the velocity, volume and size of the emitted ejecta is extremely complex. It depends on the structure and composition of the given space debris and also depends on the coupling coefficient and the total ablation rate of the debris' material.

However, over the course of the laser's ablation process, the delivered energy is almost a fixed value but the mass of the target is not fixed during this process as the ablated mass is removed from the target at the ablation rate. In this paper, the simulations have been done for two different materials, aluminium (Al) and carbon (C), as the material of the target objects, see: Fig. 8, Fig. 9, Fig. 10 and Fig. 11.

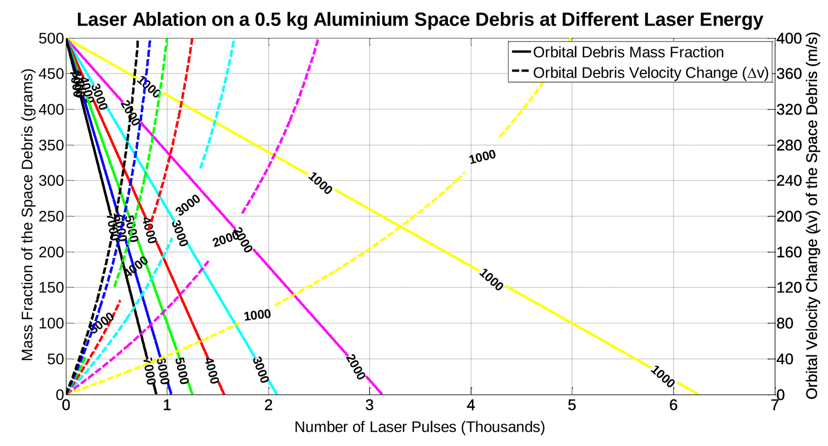

Figure 8: Laser Ablation on ½ kg aluminum space debris

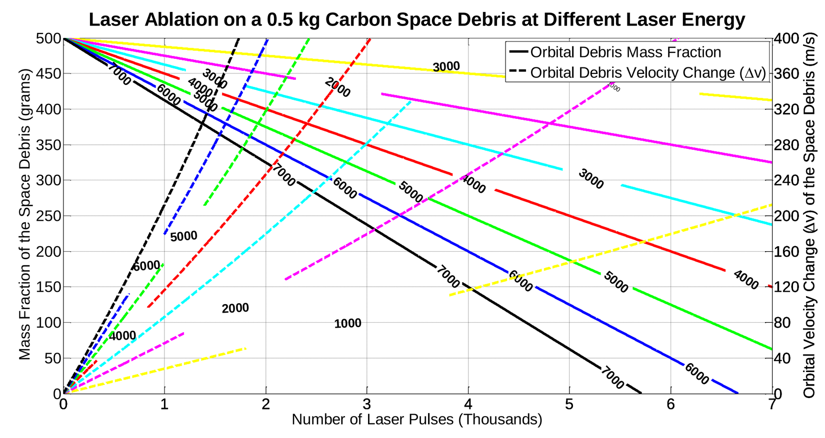

Figure 9: Laser Ablation on ½ kg carbon space debris

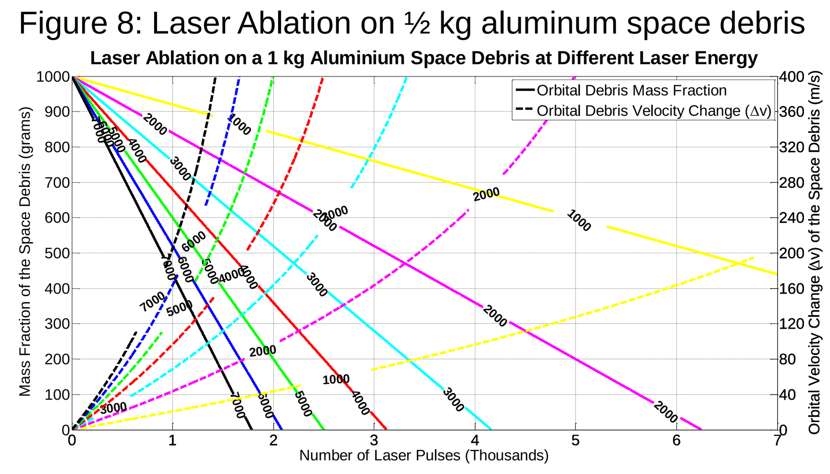

Figure 10: Laser Ablation on 1 kg aluminum space debris

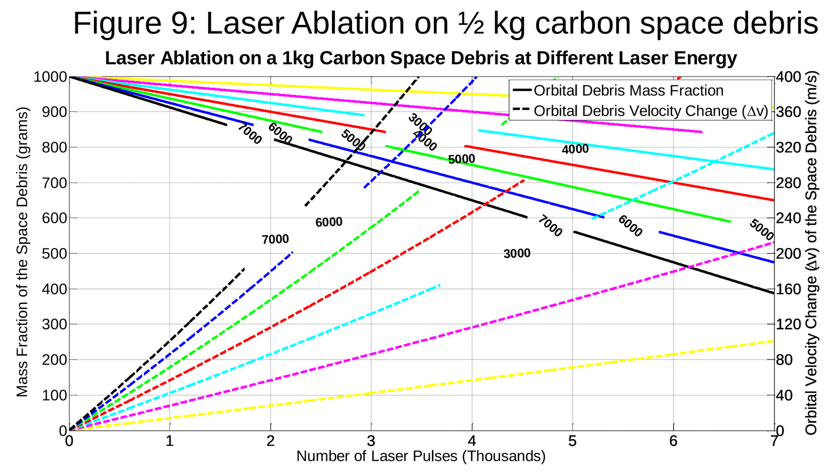

Figure 11: Laser Ablation on 1 kg carbon space debris

Conclusion

❑ Space debris in LEO poses a risk of collision with existing space systems or even with other space debris in orbit, which will generate more debris. This problem needs urgent attention and solution.

❑ Small-sized debris stays in LEO for many years before re-entering the atmosphere. However, giving this small debris a low thrust engine to move the debris to a lower altitude where drag will dominate, results in the debris losing its altitude and entering the atmosphere where it will burn up.

❑ The low thrust force can be produced by focusing a laser beam with high pulse energy onto the space debris. This generates a force that changes the altitude of the debris and reduces its orbital velocity.

❑ The theoretical results were achieved by ablating different materials of orbital debris, aluminium and carbon, with different mass (½ kg and 1 kg) using a pulsed laser. The simulation explored different pulse energies

❑ In conclusion, results have shown that the momentum transfer and the change in orbital velocity (delta-V) are sufficient to change the altitude of the debris. Therefore, this technique is viable and provides a contactless method for debris mitigation.

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